ANAEROBIC BIODEGRADABILITY OF KITCHEN WASTE

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ABSTRACT

Biodegradability of synthetic and real kitchen wastes was assessed in batch assays, under different solid contents between 1,8 and 24% and waste/inoculum ratios between 0,2 and 29 VSwaste/Vsseed sludge. Methanization rate and cumulative methane production from synthetic wastes simulated with different blends of protein, carbohydrates, fat and cellulose were compared. Although the excess of protein, carbohydrates and cellulose enhanced the biodegradability by 16 to 48%, the excess of fat reduced the maximum methane production rate and the biodegradability in 70 and 18%, respectively. The ratio waste/seed was found to be a critical parameter especially for solids content higher than 5%, since the biodegradability and the methane production rate increased significantly when the waste/seed ratio decreased from 1.35 to 0.2 g VS/gVS. The real kitchen waste was more biodegradable than the synthetic waste. However both produced methane at similar rates in batch assays for a waste/seed ratio of 1.35 gVS/gVS.

KEYWORDS

Kitchen Waste, Anaerobic Biodegradability, Waste/seed ratio

INTRODUCTION

Although Anaerobic Digestion of organic solid wastes is an established technology in Europe with more than 50 full scale plants treating more than 1 million ton per year, it represented in 1999, in average, only 5% of the total composting capacity (De Baere, 2000). In some countries, for instance in Switzerland and Belgium this value is considerably higher, 26 and 16%, respectively, whereas in other countries, AD technology is practically absent. These numbers suggest that more effort should be addressed and more research should be done to increase the AD impact in Europe.

Kitchen waste is a typical biodegradable organic waste. It is mainly composed of carbohydrates, lipids, cellulose and proteins, and its anaerobic biodegradability depends on the relative amount of each component. In general the fat fraction is the most problematic due to the toxicity of the long chain fatty acids produced by hydrolysis of lipids (Alves *et al*., 2001). Solid content and waste to inoculum ratio are important variables that affect the experimental assessment of the potential anaerobic biodegradability, being urgent to establish standard experimental procedures to enable results comparison. The solids content is one of the most important parameter that has a huge impact on the cost, performance and reliability of the digestion process. The biodegradability, COD and solids reduction under wet and dry conditions are different. “Dry” systems with highly biodegradable wastes can achieve local concentrations of inhibiting compounds and transport mechanisms in such compact solid beds are unclear. The differences between “wet” and “dry” processes are not significant in terms of investment and operational costs. “Dry” systems need costly waste handling devices such as pumps, screws and valves being compensated by a cheaper pre-treatment and reactor, which is several times smaller than for “wet” systems. The heat requirement of the “dry” systems are smaller but this usually does not represent a financial benefit, since the heat excess rarely can be sold. In terms of environmental issues the differences are more substantial since “wet” systems consume about 1 m^3 fresh water per ton of treated waste, whereas “dry” processes require about ten-fold less (Lissens *et al*., 2001).

The main objective of this work was the study of the influence of fat in the anaerobic biodegradability of kitchen waste. A synthetic waste composition, containing different ratios of protein/cellulose/starch/fat was simulated by lean meat of chicken breast, cabbage, potato flakes and melted lard of pork. Different blends were produced with an excess of each component (COD basis). In a second experiment the biodegradability of a real kitchen waste was assessed. All the batch assays were performed under different conditions of solid contents, and waste/inoculum ratio.

MATERIALS AND METHODS

Waste characterization

The synthetic kitchen waste was made by blending chicken breast, cabbage, potato flakes and lard of pork. The characteristics are presented in Table 1.

Table 1 – Characteristics of the synthetic waste components

	COD mg/g	TS mg/g	VS (mg/g)
Chicken breast	306±70	330±13	320±28
Cabbage	53±7	58±1	56±1
Potato flakes	1018±106	930±14	893±31
Fat (lard)	632±38	970±31	974±30

The real kitchen waste represented a composed sample (one week base) from the waste produced in the restaurant from the University of Minho, located in "Campus de Gualtar". It had the following characteristics: Chemical Oxygen Demand (COD): 327±73mg/gwaste, Total Solids (TS)=238.1±13.7 mg/gwaste, Volatile Solids (VS) = 213.9±7.0 mg/g waste and Total Kjeldhal Nitrogen (TKN) = 13.3±0.6 mg N-NH_4/g waste, fat content=20 mg/g waste.

Seed sludge

The seed sludge was collected from an UASB reactor belonging to a local brewery industry. The specific methanogenic activity in the presence of acetate, propionate, butyrate and H_2/CO_2 is presented in table 2.

Table 2 - Methanogenic activity of the seed sludge± 95% confidence interval

Specific methanogenic activity in the presence of (ml $CH_{4(STP)}$/gVS.day)			
acetate	**propionate**	**butyrate**	**H_2/CO_2**
346±80	187±37	40±5	493±7

Control assays (blanks), without waste, were performed in order to quantify the background methane production due to the possible residual substrate present in the seed sludge (Figure 1).

Batch experiments

Biodegradability assays were performed in vials of 160 ml and for comparative purposes two experiments were performed with flasks of 600 ml. After introducing the correct amounts of waste and seed sludge, a defined amount of anaerobic basal medium was added under strict anaerobic conditions in order to give the desirable solid content which varied between 1,8 and 23,8 %. In the latter case no basal medium was introduced in the vials in order to maximize the solids content. The vials were then incubated at 37 ºC under stirring conditions (150 rpm) and the pressure increase was monitored by using an hand held pressure transducer capable of measuring a pressure increase or decrease of two bar (0 to ± 202.6 kPa) over a range of -200 to +200 mv, with a minimum detectable variation of 0.005 bar. A sensing element consisting of a 2.5 mm square silicon chip with integral sensing diaphragm is connected to a digital panel meter module and the device is powered by a 7.5 V DC transformer. A similar technique was described by Colleran *et al,* (1992) and by Colleran and Pistilli (1994) for the assessment of specific methanogenic activity and toxicity for liquid substrates. The basal medium used in the batch experiments, made up with demineralised water, was composed of cysteine-HCL (0.5 g/L) and sodium bicarbonate (3 g/L), the pH was adjusted to 7.0-7.2 with NaOH 8N and was

prepared under strict anaerobic conditions. At regular time intervals the vials were depressurised and the biogas composition was analysed.

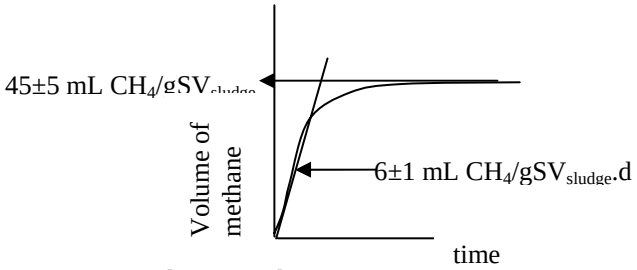

Figure 1 – Methane production per mass of seed sludge (VS) in the control (blank) assay

All batch tests, except those with the real kitchen waste, were performed in triplicate assays. The experiments with the real waste were performed in duplicate assays.

The maximum methane production rate (MMPR), was determined by the initial slope of the curve of methane production versus time. The biodegradability was determined by the maximum accumulated methane divided by the amount of waste initially present in the vial, express as COD, VS or waste weight. Methane production due to the residual substrate present in the seed sludge was discounted in all experiments. Biodegradability was also expressed by the % of methanisation relative to the Biochemical Methane Potential (BMP) which is 350 mL CH_4/gCOD at standard Temperature and Pressure (STP) conditions.

Analytical methods

Chemical Oxygen Demand (COD), volatile and totals solids (VS and TS), and Total Kjeldahl Nitrogen (TKN) were determined according to Standard Methods (APHA et al., 1989). The fat content was extracted with a mixture chloroform:methanol 1:2(v/v), dried and weighed. Methane content of the biogas was measured by gas chromatography using a Chrompack Haysep Q (80 to 100 mesh) column, with N_2 carrier gas at 30 ml/min and a flame-ionization detector. Temperatures of the injection port, column, and flame-ionization detector were 120, 40, and 130ºC, respectively.

Experimental plan

Synthetic waste

Three sets of experiments were performed with the synthetic waste. In the first one, the total COD was always the same (160 mg), but 5 different types of assays were designed in order to have a high COD contribution from each type of component, according to Table 3.

Table 3 – Experimental conditions of the batch assays with low solid content

	Assay 1		**Assay 2**		**Assay 3**		**Assay 4**		**Assay 5**	
	COD mg	TS mg	COD mg	TS mg	COD mg	TS mg	COD mg	TS mg	COD mg	TS mg
Chicken breast	40	43.1	70	75.4	30	32.3	30	32.3	30	32.3
Cabbage	40	43.5	30	32.7	70	76.2	30	32.6	30	32.6
Potato flakes	40	36.5	30	27.4	30	27.4	70	63.9	30	27.4
Fat (lard)	40	61.4	30	46.0	30	46.0	30	46.0	70	107.4
Total, mg	160	184.5	160	184.4	160	181.9	160	174.8	160	199.7
Seed sludge (mv SV)	134.4		134.4		134.4		134.4		134.4	
TS, %	1.8		1.8		1.8		1.7		2.0	
Waste/seed gVS/gVS	1,35		1,35		1,35		1,35		1,35	

The second type of assays (Nº 6 and 7) were planned to have a high solid content with equal contribution of total solids from each component (Table 4) in a total volume of 10 ml of liquid medium. However, in assay Nº 7 there was no addition of liquid, because the total moisture content of the waste was already 18.4 ml, giving a maximum solid content of 22 %. In these experiments the amount of seed sludge added to the vials was constant (134.4 g VS). This means that the ratio waste-to-seed in experiments 6 and 7 was considerably higher than in experiments 1 through 5, achieving values as high as 11 and 30 g VSwaste/gVSseed. This parameter is critical for the correct assessment of biodegradability.

Table 4 - Experimental conditions of batch assays with high solid content

	Assay 6		**Assay 7**	
	COD mg	TS mg	COD mg	TS mg
Chicken breast	348	375	933	1000
Cabbage	345	375	914	1000
Potato flakes	410	375	1095	1000
Fat (lard)	244	375	647	1000
Total, mg	1347	1500	3589	4000
Seed sludge (mgSV)	134.4		134.4	
TS, %	15		22	
Waste/seed gVS/gVS	11		30	

The third set of experiments was designed to evaluate the influence of increasing the solids content, keeping constant the ratio waste-to-seed at 1.35 gVS waste/gVSseed (Table 5).

Table 5 – Experimental conditions in the batch assays at constant waste/seed ratio.

	Assay 8		**Assay 9**		**Assay 10**	
	COD mg	TS mg	COD mg	TS mg	COD mg	TS mg
Chicken breast	117	125	233	250	933	1000
Cabbage	114	125	228	250	914	1000
Potato flakes	137	125	274	250	1095	1000
Fat (lard)	81	125	162	250	647	1000
Total, mg	449	500	897	1000	3589	4000
Seed Sludge (mg SV)	370		740		2963	
TS, %	5		10		22	
Waste/seed gVS/gVS	1.35		1.35		1.35	

Real KitchenWaste

The experiments with the real kitchen waste were planned to evaluate both the effect of solids content and the ratio waste/seed (Table 6).

Table 6 Experimental conditions in the batch experiments with the real kitchen waste

%ST	**waste/seed gVS/gVS**	**waste mgCOD**
5	0.2	687
5	1.35	687
10	0.2	1373
10	1.35	1373
24	0.2	3270
24	0.5	3270
24	1.0	3270
24	1.35	3270

RESULTS AND DISCUSSION

Synthetic kitchen Waste

The influence of carbohydrates, fat, cellulose and proteins in the biodegradability of the synthetic waste was assessed. Figure 2 (a) represents the methane production for the experiments 1 to 5 and Figure 2 (b) represents the methane production measured in experiments 6 and 7.

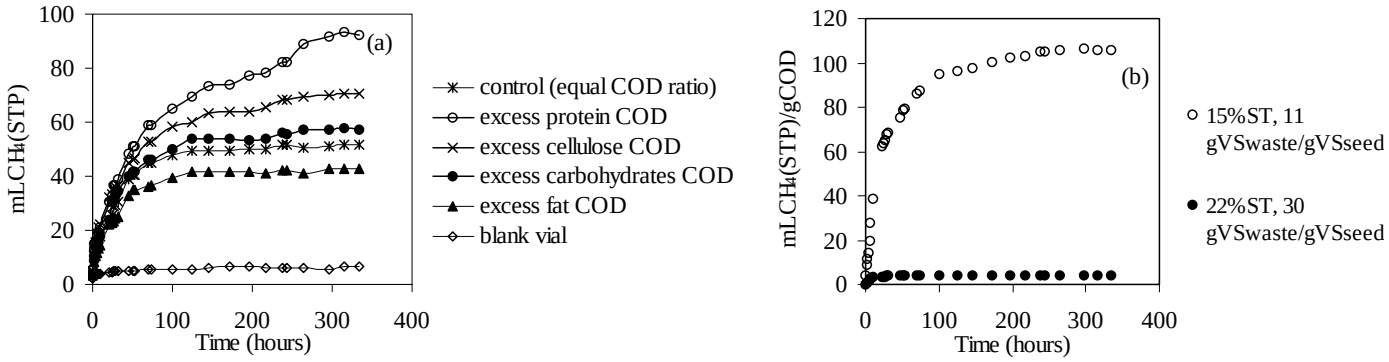

Figure 2 – Methane production in the experiments 1 to 5 (a) and in experiments 6 and 7 (b)

It is clear from Figure 2(a) that the excess of fat decreased the biodegradability of the waste. The accumulation of Long Chain fatty Acids (LCFA) that inhibit the LCFA degrading syntrophic acetogens is likely the reason of this decrease. The experiments with high solid content (15 and 22%) and low biomass concentration (Figure 2 b) revealed that, although for a waste/seed of 11 g VS/gVS some methane was produced, for a ratio of 30 gVS/gVS practically no methane was produced. This evidences the importance of this parameter in the assessment of anaerobic biodegradability of wastes and substantiates the theory of surface related kinetics hydrolysis where substrate particles are assumed to be fully covered with bacteria being these ones in excess (Sanders *et al.* 2000). These authors studied starch biodegradability in batch assays and considered waste/seed sludge ratios between 0.43 and 2.64 g COD waste/gST seed.

Figure 3 represents the results of methane production in the experiments 8 to 10 where the ratio waste/seed was kept constant at 1.35 gVS/gVS. As the amount of waste was different in each vial, the methane production curves are presented per g of waste COD initially present. For one of the experiments (22%ST), two types of vials were used to evaluate the influence of the vial volume in the measured biodegradability. Similar amounts of seed sludge and waste were placed inside vials of 160 mL and 600 mL. Theoretically the obtained results would be similar. However, it was observed that in the bigger vial a significantly higher biodegradability was measured, likely on account of the higher contact between the waste and the seed sludge, promoted by stirring and by the higher available head space volume. On the other hand the big vials also provided higher waste-gas interfacial area for gaseous products transfer. The results obtained in the blank control vials are not presented in Figure 3, but the final corrected values of methane production rate and biodegradability are presented in Table 7 which presents the calculated maximum methane production rate, the biodegradability and the % of methanisation for experiments 1 to 10.

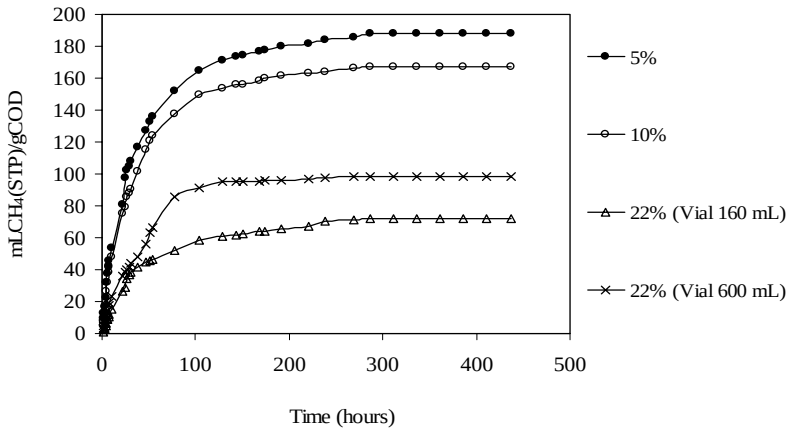

Figure 3 – Methane production per gCOD for 5, 10 and 22% ST and waste/seed =1.35 gVS/gVS (experiments 8 to 10). Blanks were not discounted in these curves.

Table 7 – Summary of experiments 1 to 10

Assay #	Experimental conditions protein/cellulose/carbohydrates/fat COD (%ST, gVSwaste/gVSseed)		MMPR ml CH_4/gCOD.d	Biodegradability mLCH$_4$/gCOD	mL CH_4/gVS	%methanisation
1	40/40/40/40	(1.8, 1.35)	266±32	272±6	274±62	78±2
2	70/30/30/30	(1.8, 1.35)	316±34	403±67	362±61	115±19
3	30/70/30/30	(1.8, 1.35)	380±37	397±63	357±57	114±18
4	30/30/70/30	(1.8, 1.35)	211±22	317±1	333±62	91±1
5	30/30/30/70	(1.8, 1.35)	76±2	221±21	180±16	63±6
6	348/345/410/244	(15, 11)	82±7	101±12	93±11	29±3
7	933/914/1095/647	(22, 30)	9±3	3±1	5±5	1±1
8	117/114/137/81	(5, 1.35)	132±6	156±4	142±2	44±1
9	233/228/273/161	(10, 1.35)	123±6	133±10	122±9	38±3
10(vial 160mL)	933/914/1095/647	(22, 1.35)	31±1	36±2	33±2	10±1
10 (vial 600 mL)	933/914/1095/647	(22, 1.35)	50±2	64±4	58±3	18±1

The mixtures at low solid content and with excess of protein, cellulose or carbohydrates were completely biodegraded since the % methanisation obtained by comparison with the biochemical methane potential were near 100%. When an excess of protein, cellulose or carbohydrates was present, the methane production rate was enhanced relatively to the excess of fat. As above mentioned, the excess of this late component significantly inhibited the methane production rate and the waste biodegradability allowing a maximum methanisation of 63%.

The experiments with 15 and 22% total solids but with limited seed sludge gave values of very low biodegradability with 30% and 0.7% methanization for 11 and 30 gVSwaste/gVSseed, respectively. The assays performed with higher amounts of seed sludge showed higher biodegradability but a significant influence of the vial volume was observed.

Real Kitchen Waste

Figure 4 shows the results obtained for the methane production per gCOD with the real kitchen waste. A comparison was made for each %ST between the different ratio waste/seed tested (Figure 4 a,b,c).

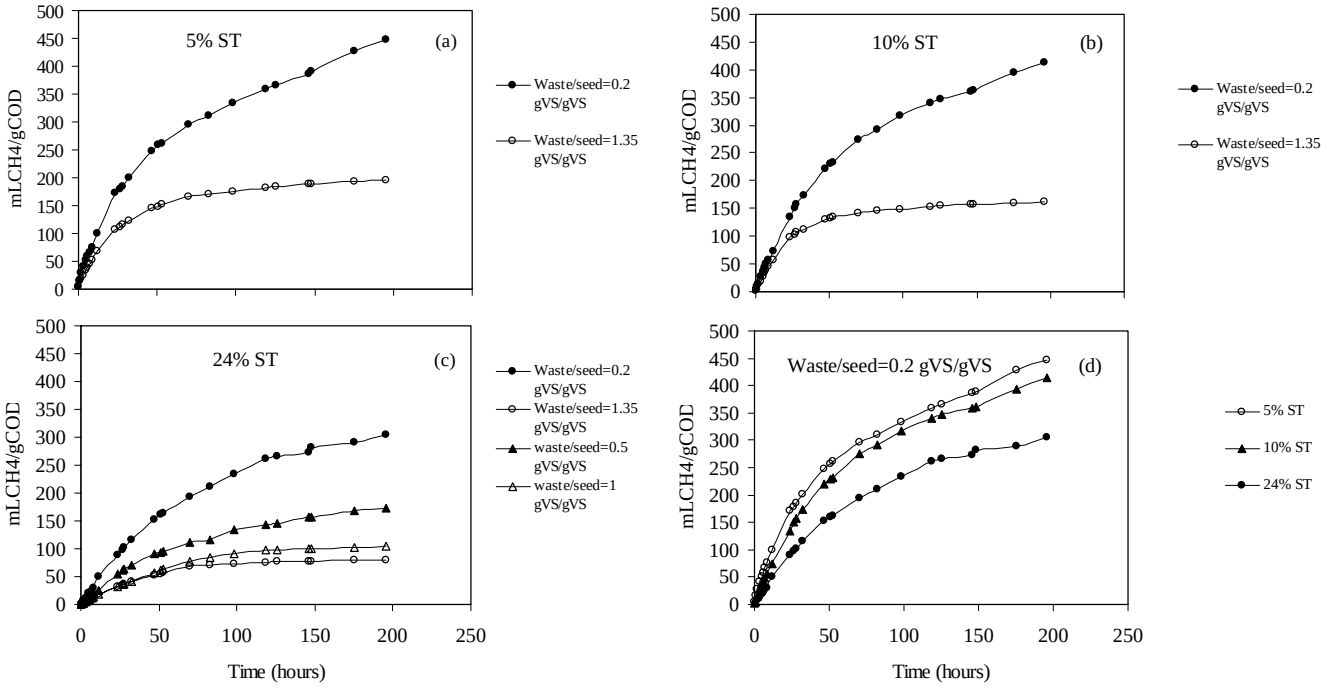

Figure 4 – Results of batch assays with the real kitchen waste. Experiments with 5%ST (a), 10%ST (b) and 24%ST(c). Comparison between the 5, 10 and 24%ST for the ratio waste/seed of 0.2 gVS/gVS. Blanks were not discounted in these curves.

The choice of these values of waste/seed was in part based on the opinion of Salminen et al., (2000) who referred values between 0.2 and 0.93 for the assessment of the solid poultry slaughterhouse biodegradability. In these experiments a big amount of seed sludge, up to 10.7 gSV was added to the vials, being very important the correction of the methane production from the residual substrate. For instance, for the vial with 5%ST and 0.2 waste/seed, the methane production from the residual substrate reached a value as high as 100 mL CH4, corresponding to 146 mLCH_4/gwaste COD initially present in the vial. This explains the high values of methane produced, which exceeded the theoretical biochemical methane potential. Table 8 summarises the results obtained in these experiments, where all the values are already corrected by the blank control assays.

The ratio waste/seed influenced significantly both the maximum methane production rate and the biodegradability of the waste. A continuous decrease of these variables was observed for the assays with 24% ST when the waste/seed ratio increased from 0.2 to 1.35 (Table 8).

Table 8 – Summary of the biodegradability batch experiments with the real kitchen waste

%ST	**waste/seed**	**MMPR**	**biodegradability**		**% methanization**
	gVS/gVS	mL CH_4/gCOD.d	mL CH_4/gCOD	mL CH_4/gSV	
5	0.2	181±1	300±5	460±8	86±1
5	1.35	126±6	174±4	266±5	50±1
10	0.2	148±15	268±19	409±28	76±5
10	1.35	116±11	177±8	270±12	50±2
24	0.2	78±21	159±7	242±11	45±2
24	0.5	47±7	115±7	176±11	33±2
24	1.0	30±1	75±23	115±34	22±6
24	1.35	28±2	58±1	89±2	17±2

It is interesting to evaluate the influence of solids content on the MMPR and on the biodegradability for two different ratio waste/seed (Figure 5), considering all the experiments.

Under the range between 5 and 25 %ST there is a significant enhancement in the methane production rate and on the biodegradability by increasing the amount of seed sludge. For lower solid content (below 5%) it is expect that the influence of the amount of seed sludge will not be so important, since the biodegradability is already near the BMP.

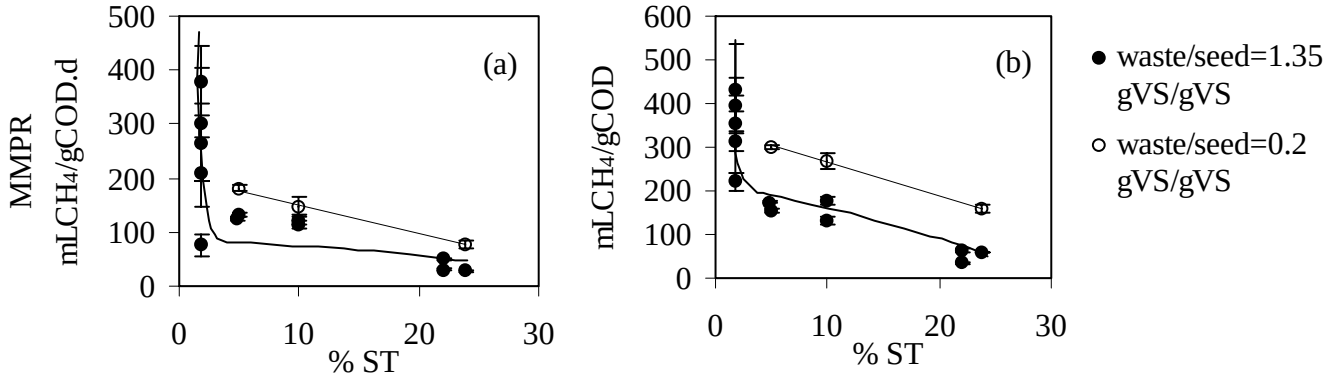

Figure 5 – Influence of the solids content on the Maximum methane production rate (a) and on the biodegradability (b) for 0.2 gVSwaste/gVSseed and for 1.35 gVSwaste/gVSseed

These results put in evidence the problems of mass transport inside compact beds of solid wastes. Besides potential inhibition due to local accumulation of metabolites, dry systems efficiency will depend very much on the excess of seed sludge, probably because transport and diffusion of substrates and products are hindered by the low moisture content. The comparison between the two types of waste tested in this work is presented in Figure 6 for a similar ratio waste/seed of 1.35g VS/gVS. The maximum methane production

rate was similar for both types of waste, but the biodegradability of the real waste was significantly higher than that of the synthetic one. The lower fat content of the real kitchen waste (84 mg fat/gSTwaste for the real waste and 250 mg fat/gSTwaste for the synthetic one) can explain the different biodegradabilities obtained.

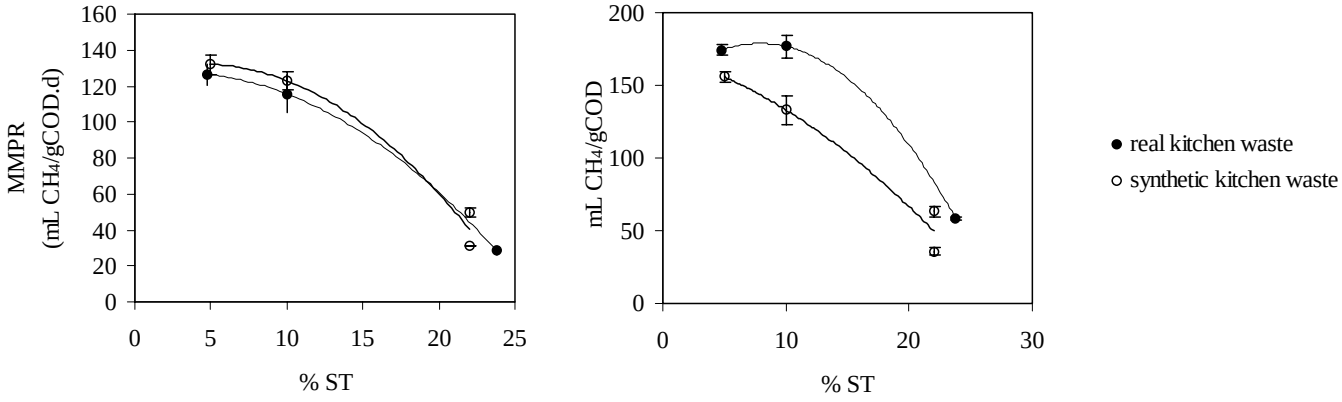

Figure 6 – Comparison between the maximum methane production rate (a) and the biodegradability (b) of the synthetic and the real kitchen waste. Waste/seed constant at 1.35 gVS/gVS.

CONCLUSIONS

The biodegradability of synthetic and real kitchen wastes was assessed in batch assays, under different solid contents between 1.8 and 24% and different waste/seed ratio between 0.2 and 30 gVS/gVS. Methanization rate and cumulative methane production from synthetic wastes simulated with different blends of protein, carbohydrates, fat and cellulose were compared. Although the excess of protein, carbohydrates and cellulose enhanced the biodegradability of the synthetic waste by 16 to 48%, the excess of fat reduced the maximum methane production rate and the biodegradability in 70 and 18%, respectively. The ratio waste/seed was found to be a critical parameter especially for a solid content higher than 5%, since the biodegradability and the methane production rate increased significantly when the waste/seed ratio decreased from 1.35 to 0.2 gVS/gVS. The real kitchen waste was more biodegradable than the synthetic one. However both produced methane at similar rates in batch assays for a waste/seed ratio of 1.35 gVS/gVS.

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